



**Fermilab**  
ES&H Section

December 27, 1994

TO: David Finley  
Roger Dixon

FROM: Don Cossairt *DC*

SUBJECT: Groundwater Activation Calculations, EP Note 8

Please find enclosed the documentation of my proposal of procedures to employ to use the new "Concentration Model" to perform groundwater radioactivation calculations. My recommendation has been approved by the Director and this approval is included in the documentation. This is now the procedure that should be followed henceforth for such calculations. This approval was granted at the conclusion of a meeting attended on December 22, 1994 by R. Walton, R. Rameika, K. Stanfield, R. Stefanski, R. Walton, J. Peoples, and I. Provisions for consideration of "special cases" is included in the recommendation as approved. The intensive efforts of the *ad hoc* working group in this area capably led by A. Wehmann and A. Malensek is most appreciated. We will soon be revising the Fermilab Radiological Control Manual to reflect this new procedure.

I would appreciate it if you would make individuals within your organization who are involved with such calculations but who may not be included in the distribution below aware of this matter.

Encl.

cc w/o encl.:

J. Peoples  
R. Rameika

cc w/encl.:

SSO's  
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File: EP Note 8  
Groundwater Monitoring

**ENVIRONMENTAL PROTECTION NOTE 8**

**USE OF A CONCENTRATION-BASED MODEL FOR  
CALCULATING THE RADIOACTIVATION OF SOIL AND  
GROUNDWATER AT FERMILAB**

**J. Donald Cossairt**

**December 1, 1994**

**ABSTRACT**

The results of the recent groundwater study conducted at Fermilab have been reviewed and documented elsewhere. The present report summarizes the principal conclusions and makes a specific recommendation to the Fermilab Director concerning the application of the results of these studies to the future design of beam targets and absorbers at Fermilab.

(Approvals on page 26)

## 1. Introduction

The normal operations of large particle accelerators are capable, under certain conditions, of producing radionuclides in the adjacent soil. These radionuclides can potentially migrate to groundwater supplies. The production of these radionuclides is dependent upon the beam parameters (energy, particle type, intensity, and target configuration) while the soil activation and migration to groundwater is dependent upon the details of the local hydrogeology. It is thus necessary to design accelerator shielding in a way which takes such migration into account. Over the years at Fermilab, a "standard" model has been used to perform such calculations. Recently, a new model has been developed with a view toward resolving some problems raised by the long-standing method. Section 2 summarizes the historical background concerning the development of these models. Section 3 reviews the applicable regulatory and U. S. Department of Energy requirements. Sections 4, 5, and 6 summarize and compare the features of the two models. Section 7 presents a detailed comparison of calculations made using the two models. Finally, Section 8 presents a recommendation to the Director on this subject.

## 2. Historical Background

Throughout its history, the Fermi National Accelerator Laboratory has demonstrated a concern with respect to the radioactivation of soil and groundwater through the interaction of accelerated protons and secondary particles in the beam absorbers and sometimes elsewhere through routine beam losses. These particle interactions generate "hadronic cascades" of energetic secondary particles sometimes referred to as "showers." These secondary particles are capable of inducing radioactivity by means of nuclear reactions and are spread spatially over the immediate vicinity of the point of interaction as the shower proceeds. The radioactivity produced in these reactions can, under certain conditions, be produced in the soil surrounding such beam absorbers and then can conceivably propagate to groundwater.

That such radioactivation at a large proton accelerator was a concern was recognized early in the history of Fermilab by M. Awschalom (Aw 71). Measurements of the macroscopic activation cross sections performed in support of the work of Awschalom were made by T. Borak, et. al. (Bo 72). In Ref. (Bo 72) it is determined that only two accelerator-produced radionuclides;  $^3\text{H}$  and  $^{22}\text{Na}$ , may significantly impact groundwater resources. This work led to the development of what has been called the "Single Resident Well Model" (hereafter called "the SRWM"). As time passed, increased experience and regulatory changes concerning drinking water standards led to modifications of the SRWM. The clearest statement of the version of the SRWM model as it has been used since 1978 was documented by P. Gollon (Go 78) and is based upon background work performed by S. Baker. This model was developed and used in

the belief that it represents a conservative<sup>1</sup> approach which leads to the design of beam absorber shielding in a way which renders it improbable for Fermilab operations to result in violations of drinking water standards<sup>2</sup>. The use of the SRWM as a "standard" model has also resulted in a general consistency in shielding design over time.

Recent design efforts have led to a reexamination of the underlying assumptions of the SRWM. Some of these assumptions have been questioned and have generated observations that the SRWM might be "overly conservative" (Jo 78). On the other hand, questions have been raised that can even lead to the conclusion that not all assumptions inherent in the SRWM are necessarily "conservative," as will be seen below. Furthermore, with advent of upgrades to the Fermilab accelerator complex, higher intensity beams will be available and with some of the associated new directions of the physics research program, the innovations in the "styles" of shielding design employed may require the examination of hydrogeology in more detail.

To further study this subject the Research Division and the Environment, Safety, and Health Section established a joint *ad hoc* committee<sup>3</sup>. This committee was charged with re-examining the methodology of calculating the radionuclide production and transport in groundwater in the vicinity of the various existing and potential sources on the Fermilab site. To proceed with this study, the committee arranged for the employment of a consulting firm, Woodward-Clyde Consultants, which has well-known credentials in the field of groundwater studies. The consulting firm applied state-of-the-art analytical and geological methods, similar to those used in the evaluation and analysis of modern landfill design, to address radionuclide migration under conditions present at Fermilab.

In August 1993, Woodward-Clyde completed their report (WCC 93). Based upon these results the *ad hoc* committee has prepared two reports which present an alternative model, described as a "Concentration Model" (hereafter called "the CM") in TM-1850 (We 93) and TM-1851 (Ma 93). The Woodward-Clyde study used existing geological data to evaluate seven existing or potential sources of radionuclide production at Fermilab. These are denoted AP0 (Antiproton Source), A0 (Antiproton Abort), MI40 (Main Injector Abort), C0 (Main Ring/Tevatron Abort), P (Proton Area), N (Neutrino Area), and NUMI (the proposed Main Injector neutrino beam production target).

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<sup>1</sup>The term "conservative" in this report always means the choice or set of choices of assumptions or parameters which will lead to the largest possible concentrations of radioactivity at the end point of concern, usually in drinking water.

<sup>2</sup>The most clear statement of the SRWM is found in a report documenting the analysis of a beam absorber that was never used (i.e., the antiproton production target with its extraction point at F-25).

<sup>3</sup>The members of this *ad hoc* committee are A. J. Malensek, A. A. Wehmann, A. J. Elwyn, K. J. Moss, and P. M. Kesich.

TM-1850 and TM-1851 present a methodology for estimating radionuclide production in soil and migration in groundwater. The hydrogeologic modeling performed by Woodward-Clyde relies on knowledge of the soil and rock strata underlying Fermilab. However, the detailed configuration of glacial sediments present in the vicinity of Fermilab are variable by nature and difficult to understand with absolute certainty at any given location.<sup>4</sup> This "incomplete knowledge" is reflected in the results of the modeling such that key parameters of the CM are presented as "domains" from which one must choose a given value to perform a calculation. Since the effects of both diffusion and radioactive decay are involved, the ranges of values of the parameters used in a given calculation can lead to variations of several orders of magnitude in the calculated concentrations. Thus the Laboratory must choose the parameters. The purpose of this report is to recommend choices of these parameters to use when performing "standard" calculations and to recommend future courses of action that might be undertaken to reduce the uncertainties.

### 3. Summary of EPA and IEPA Regulatory Requirements and DOE Orders

The protection of groundwater resources from contaminants of all types is, of course, a major priority in the protection of people and the environment. The U. S. Environmental Protection Agency (EPA) has established regulations governing drinking water supplies in 40 CFR Part 141. Current regulations specify the maximum concentration in "public" drinking water supplies for the single accelerator-produced radionuclide,  $^3\text{H}$ . The only other radionuclide regulated by the present table is  $^{90}\text{Sr}$ , which is not produced by accelerators<sup>5</sup>. The present limit for  $^3\text{H}$  is 20 pCi/cm<sup>3</sup> and is based upon the delivery of 4 mrem per year to typical individuals who use water of this concentration for their normal source of household drinking water<sup>6</sup>.

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<sup>4</sup>The geological formations underlying the Fermilab site are well-known and relatively simple but are subject to unknown local variations due to typical glacial sedimentary variability. It is not possible to make boring tests at every possible point around a source to determine the actual strata present.

<sup>5</sup>EPA, in FR 33050-33127, July 18, 1992, published proposed drinking water standards for radionuclides that will, when finalized, give specific limits for a large number of radionuclides. These will replace portions of the present 40 CFR Part 141. The proposed limit for  $^3\text{H}$  is 60.9 pCi/cm<sup>3</sup> while that for  $^{22}\text{Na}$  is 0.466 pCi/cm<sup>3</sup>. It is likely to be several years before these new limits are in effect so that compliance must presently be with the existing regulations.

<sup>6</sup>Given the nature of water utilization in the immediate vicinity of Fermilab, all drinking water is assumed to originate from groundwater, rather than surface water sources.

The U. S. Department of Energy gives specified limits for surface water discharges of radionuclides in DOE Order 5400.5 (DOE 90)<sup>7</sup>. These concentrations are based upon delivery of an annual effective committed dose of 100 mrem to an average person who utilizes such a surface water discharge as his sole source of household water. These are known as the Derived Concentration Guides (DCGs). DOE Order 5400.5 also gives guidance on the use of the concentrations specified therein "... to provide a level of protection for persons consuming water from a public drinking water supply ... that is equivalent to that provided to the public by the ... drinking water standards of 40 CFR Part 141." DOE 5400.5 does this by using four per cent of the concentration equivalent to delivery of 100 mrem/year (the tabulated DCG value) to determine the concentration that is deemed to deliver 4 mrem/year. In all such determinations where multiple radionuclides, say  $n$  in number, are involved, both DOE and EPA require that the sum of the actual concentrations,  $C_i$ , divided by the applicable "regulatory concentration guide,"  $G_i$ , be less than or equal to unity as expressed by Eq. (1):

$$\sum_{i=1}^n \frac{C_i}{G_i} \leq 1. \quad (1)$$

For convenience, the various values of  $G_i$  are given in Table 1. The most stringent limit (EPA or DOE) for the water type at risk ("surface discharge" or "drinking") is used to assure compliance with both the regulations and the DOE order.

**Table 1 Values of  $G_i$  (pCi/cm<sup>3</sup>)**

Regulation	Water Use Type	Annual Dose Equivalent (mrem)	<sup>3</sup> H	<sup>22</sup> Na
40 CFR Part 141	Drinking	4	20	0.2 <sup>8</sup>
DOE Order 5400.5	Surface	100	2000	10
DOE Order 5400.5	Drinking	4	80	0.4

In November of 1991, the Illinois Environmental Protection Agency (IEPA) issued Ground Water Quality Standards (GQS) (35 Ill. ADM. CODE 620). The GQS set limits for contaminants in Class I groundwater. Class I is the new State

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<sup>7</sup>These requirements and standards are being incorporated in the Proposed Federal Rule 10 CFR 834 which is anticipated to be made final in the next year or so.

<sup>8</sup>This value has been used at Fermilab for many years in performing calculations using the SRWM. It was inferred from references cited in 40 CFR 141 for radionuclides not included in the table that has <sup>3</sup>H and <sup>90</sup>Sr as the only entries. Given the lack of specific EPA limits and the availability of the DOE 5400.5 DCGs, in recent years the value derived from the DCGs of DOE 5400.5 (0.4 pCi/cm<sup>3</sup>) have been used for <sup>22</sup>Na in SRWM calculations.

of Illinois designation for potable groundwater supplies. These standards include a specific maximum contaminant level (concentration) for  $^3\text{H}$  of 20 pCi/cm<sup>3</sup>, equivalent to the 40 CFR Part 141 standard. In this new classification scheme it apparently makes no difference if the groundwater is presently being used, or is planned to be used in the future, as a drinking water resource. The standard is implemented to protect groundwater resources against degradation and it does not appear to allow for dilution, decay, or other methods to reduce the contamination of contaminants.

It is important to understand how these IEPA standards affect Fermilab. It is our present interpretation that the uppermost stratigraphic horizon, the glacial till sediments, are not Class I groundwaters but that the underlying till/dolomite transition horizon and the dolomite unit are Class I groundwater zones. As a result of this interpretation it is believed that the amount or concentration of  $^3\text{H}$  in the till near the present Fermilab beam absorbers is a non-regulatory issue. However, because the underlying units (till/dolomite transition and dolomite strata) are clearly Class I groundwaters, assurance must be provided that Fermilab does not exceed the tritium concentrations in these units. This recent regulatory development, as described below, has considerable effect upon how the CM is used.

#### **4. Summary of the SRWM**

TM-1851 presents a synopsis of the SRWM which, for convenience, is largely repeated here. In this model, the sum of all the leached radionuclides in the unprotected region produced annually gets transported to one well (located in the dolomite), where it mixes with the daily volume of water that is used by a single resident under drought conditions, taken to be 40 gallons/day. Vertical flow in the glacial till, the sediments above the dolomite, is taken to be 2.2 m/yr. (7.2 ft/yr.) for  $^3\text{H}$  and 0.9 m/yr. (3.2 ft/yr.) for  $^{22}\text{Na}^9$ . The horizontal flow in the aquifer (dolomite) to the hypothetical well is taken to be instantaneous. Radioactive decay is applied to the vertical flow based upon the distance between the aquifer (taken as elevation 206 meters or 677 feet above mean sea level) and the lowest elevation of the "unprotected" region directly beneath the source. As used in this model, the "unprotected" region is defined to be that region external to enclosure walls or "bathtubs" where the radionuclides produced can freely migrate in three dimensions according to the local geology. In most

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<sup>9</sup>The postulation of these migration velocities near the upper bound of possible, not necessarily probable, values are not completely conservative. It does not allow for the existence of so-called "sand lenses." Such formations of saturated granular material allow for locally rapid migration of water. Near Fermilab such formations are usually horizontal, rarely continuous over long distances, and seldom are sufficiently sloped to contribute to rapid vertical migration. According to section 3.3.1 of Ref. (WCC 93), "sand layers are not found to be continuous at any of the target areas nor across the entire site."

circumstances, volumes of granular material drained by "underdrains" are considered "protected," rather than "unprotected" regions of soil in the SRWM.

The SRWM uses Eq. (2) to determine the concentrations of  $^3\text{H}$  and  $^{22}\text{Na}$  to be compared with the drinking water limits. The SRWM does not apply to surface water discharges because the "artificial" assumption of the dilution of the total annual production of radioactivity by the annual consumption of a single user effectively occurs at the till/dolomite interface. The concentration of the  $i^{\text{th}}$  radionuclide,  $C_i$ , at the well used by this hypothetical person is given by:

$$C_i \text{ (pCi / ml - yr)} = \frac{N_p(\text{proton / yr})S_T(\text{stars / proton})K_iL_i(\text{atoms / star})\exp\left[-y/v_i\tau_i\right]}{\tau_i(\text{yr})(6.47 \times 10^{13})}. \quad (2)$$

In Eq. (2);

$N_p$  = number of protons per year incident on the source target station,

$S_T$  = the total stars<sup>10</sup> per proton summed over the unprotected region,

$K_i$  = nuclide production rate (atoms/star) for the  $i^{\text{th}}$  nuclide,

$L_i$  = leachability factor for the  $i^{\text{th}}$  nuclide,

$y$  = vertical distance from the source to the aquifer (meters),

$v_i$  = vertical velocity for the  $i^{\text{th}}$  nuclide (meters/year),

$\tau_i$  = mean life of the  $i^{\text{th}}$  nuclide (yr.), and

$6.47 \times 10^{13}$  = converts disintegrations per second into picoCuries (0.037), years into seconds ( $3.15 \times 10^7$ ), and 40 gallons per day for 1 year into  $\text{cm}^3$  ( $5.55 \times 10^7$ ).

The radionuclide production of total stars per proton is typically obtained at Fermilab by using the Monte Carlo program CASIM (Va 75). In using this program, the star densities are numerically integrated over the volume of "unprotected soil" to obtain the total stars per incident proton,  $S_T$ . The above formula is then employed to determine the concentrations of each of the two radionuclides of interest at the location of the hypothetical users of the well. These are compared with the standards by means of Eq. (1) to determine the adequacy of the designed groundwater shield. In general practice at Fermilab, each beamline has been considered independent of all of the others. The fact that a single well could theoretically receive water influenced by multiple sources is not taken into account.

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<sup>10</sup>In the terminology of hadronic cascades, a "star" represents a high energy particle interaction. The Monte-Carlo programs written to model such hadronic cascades typically tabulate the production of stars as a function of location within the shower as the most basic result of a given calculation.

## 5. Summary of the CM

TM-1851<sup>11</sup> goes into great detail to describe the proposed new model, a level of detail not duplicated here. In essence, the model calculates an "initial concentration" external to the shielding. This initial value can readily be compared with surface discharge limits. This concentration is then transformed into the estimated concentration at the site of a potential drinking water user employing dilution factors obtained from the results of Ref. (WCC 93). Equation (3) is used to calculate the initial concentration of the  $i^{\text{th}}$  individual radionuclide,  $C_{oi}$ , that would be found in the soil volume immediately external to the shielding:

$$C_{oi} \left( \frac{\text{pCi}}{\text{cm}^3 - \text{yr}} \right) = \frac{N_p [(0.019) S_{\max}] K_i L_i}{[1.17 \times 10^6] \rho_s w_i} \quad (3)$$

In Eq. (3);

$N_p$  = number of protons per year incident on the source target station,

$S_{\max}$  = maximum stars per  $\text{cm}^3$  per proton in the unprotected soil,

$K_i$  = nuclide production rate (atoms/star) for the  $i^{\text{th}}$  nuclide,

$L_i$  = leachability factor for the  $i^{\text{th}}$  nuclide,

$\rho_s$  = density of soil (till)  $\text{g}/\text{cm}^3$ ,

$w_i$  = the weight of water divided by the weight of soil that corresponds to a selected percentage of leaching,

0.019 = factor used to convert  $S_{\max}$  to the average star density<sup>12</sup>, and the factor

$1.17 \times 10^6$  = converts disintegrations per second into picoCuries (0.037), years into seconds ( $3.15 \times 10^7$ ).

As stated in TM-1851, regions "drained" by using underdrains external to devices such as "bathtubs" are not considered to be "protected soil" in this model. In the development of the SRWM, it was thought, with considerable naïveté, that water in media consisting of such "granular fill" would always move with high efficiency toward the underdrains. As described in TM-1851, this occurs with certainty only under conditions of saturated soil. When soil is unsaturated, water may actually travel around the sand and gravel volume and thus bypass the underdrains. Since it is not known with certainty whether the entirety of such volumes are saturated, it does not appear to be appropriate to count such regions as "protected soil."

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<sup>11</sup>This is done on pp. 19-21 and pp. 60-64.

<sup>12</sup>This numerical value is derived in TM-1851 which used a parameterization of CASIM results to convert  $S_{\max}$  (usually as found immediately external to the shield) to the average that would be found within the volume bounded by the surface at which the star density is equal to  $0.01 S_{\max}$ . Typically, this volume extends outward radially by 1.84 meters. The volume so-defined is called "the 99% volume" in TM-1851 and henceforth in this report.

In contrast to the SRWM, the CM calculates  $C_{oi}$  at the saturation value for each radionuclide considered, rather than simply using the annual production. It also makes possible the predictions of concentrations in sumps and underdrains that are not possible with the SRWM by comparing  $C_{oi}$  to surface water limits using Eq. (1).<sup>13</sup> After the calculation of  $C_{oi}$ , the results of Ref. (WCC 93) are used in the CM to calculate the "final" concentration of the  $i^{\text{th}}$  individual radionuclide,  $C_{fi}$ , at the site of some hypothetical user. This is done by means of Eq. (4):

$$C_{fi} \left( \frac{\text{pCi}}{\text{cm}^3 \text{ yr}} \right) = C_{oi} R(\text{Till}) R(\text{Mix}) R(\text{Dolomite}). \quad (4)$$

In Eq. (4), the reduction factors,  $R$ , (described for Fermilab-specific media) are;

$R(\text{Till})$  = the reduction due to vertical migration and radioactive decay occurring during transport to the glacial till from the lowest boundary of the "99% volume" to the top of the dolomite aquifer,

$R(\text{Mix})$  = the reduction due to the mixing of the water containing the accelerator-produced radioactivity with other water at the glacial till/dolomite interface, and

$R(\text{Dolomite})$  = the reduction due to the mixing and radioactive decay occurring in the transport to the Fermilab site boundary or nearest downgradient well.

These reduction factors are obtained directly from the results of Reference (WCC 93). In general,  $R(\text{Till})$  is dependent upon the parameter  $d$ , the vertical distance between the zone where activation occurs and the top of the dolomite. It is recommended in TM-1851 that the parameter  $d$  be measured at the outer boundary of the so-called "99% volume" and hence from a point 1.84 meters below the beginning of the lowest portion of the soil outside of the enclosure to the dolomite.  $R(\text{Mix})$  and  $R(\text{Dolomite})$  are likewise location and geometry dependent as stated in TM-1851.

With these reduction factors, one can calculate the final concentrations,  $C_{fi}$ , which must then be compared with the appropriate regulatory limits for drinking water by means of Eq. (1). The nature of the CM renders sources "independent" of each other. That is, if multiple sources are spatially separated sufficiently to assure that their respective "99% volumes" do not overlap, the combined concentrations due to mixing from the multiple sources will be less than that of the source producing the highest concentration. The discussion of the details of the reduction factors is given in TM-1851 is not repeated here. The most significant decisions which must be made concerning the use of the CM at Fermilab are of choices from the range of values for  $R(\text{Till})$ ,  $R(\text{Mix})$ , and  $R(\text{Dolomite})$  presented.

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<sup>13</sup>Implicit is the assumption that one can "average" over the volume of "unprotected" soil immediately adjacent to a beam absorber, i.e., over the "99 per cent volume."

## 6. Comparison of Features of the SRWM with Those of the CM

Table 2 compares the assumptions and features of the two models and the corresponding advantages and disadvantages of each.

**Table 2**  
**Comparison of Features of SRWM and CM**

<b>Single Resident Well Model</b>	<b>Concentration Model</b>
<b>Calculation is based on <math>S_T</math></b>	<b>Calculation is based on <math>S_{max}</math></b>
<p><u>Advantages:</u> This is an integral quantity that can be calculated with rather small statistical error.</p> <p><u>Disadvantages:</u> The choice of volume of "unprotected" soil is often limited by calculational practicalities.</p>	<p><u>Advantages:</u> One is not required to devise an "arbitrary" volume in a cascade calculation which may miss significant contributions to the numerical integration involved in the SRWM. Also, using <math>S_{max}</math> intrinsically leads one to the quantity of concern, the radionuclide concentration.</p> <p><u>Disadvantage:</u> Some skill is required to identify a statistically precise value of <math>S_{max}</math>. Local averaging near the maximum to obtain an estimate of <math>S_{max}</math> with better statistical validity can alleviate this potential problem.</p>
<b>Calculation allows for "protected" soil zones.</b>	<b>Calculation does not allow for "protected" soil zones.</b>
<p><u>Advantage:</u> One can take credit for the use of underdrains.</p> <p><u>Disadvantage:</u> The "protective" ability of underdrains as used in these calculations is rendered suspect by improved understanding resulting from the work of the Woodward-Clyde Consultants.</p>	<p><u>Advantage:</u> One is not taking credit for the sometimes "unsubstantiated" protection allegedly provided by underdrains.</p> <p><u>Disadvantage:</u> There is no credit for protection that might be afforded by "saturated" granular fill areas.</p>
<b>Calculation is based on annual production by <math>N_p</math> protons.</b>	<b>Calculation is based on "saturation" activity produced by annual delivery of <math>N_p</math> protons.</b>
<p><u>Advantage:</u> Appears to accommodate programmatic variations.</p> <p><u>Disadvantage:</u> Ignores buildup of radioactivity near beam absorbers which is known to be occurring because of the known slow vertical movement of water.<sup>14</sup></p>	<p><u>Advantage:</u> Accommodates saturation of radionuclides in soil near beam absorbers from multiple years of beam operations.</p> <p><u>Disadvantage:</u> Taking the peak (saturation) value of <math>N_p</math> for the source term for a typical year of actual operation is too severe given the nature of Fermilab operations, in particular the long shutdowns of the fixed-target areas which are now measured in multiple years. However, this can be handled by setting <math>N_p</math> to the anticipated "average" annual delivery over a number of years.</p>

continued-next page

<sup>14</sup>See Ref. (WCC 93) and recent editions of the annual Fermilab Site Environmental Report.

Table 2 (continued)

Single Resident Well Model	Concentration Model
Calculation gives concentration at drinking water receptor location only.	Calculation gives concentrations both adjacent to beam absorbers and at drinking water receptor locations.
<u>Disadvantage:</u> Can obtain no information concerning concentrations in sump discharges and hence discharges into surface waters.	<u>Advantage:</u> Can, in principle, calculate concentrations at any location. In particular, concentrations in surface water discharges can be obtained.
Calculations, as performed in practice, consider each source independently of all others.	The contributions of multiple sources are "automatically" considered.
<u>Advantage:</u> Each source can be designed independently.	<u>Advantage:</u> All sources that might affect an individual drinking water user are taken into account.
<u>Disadvantage:</u> Contributions of multiple sources at the same receptor site are ignored, perhaps sometimes nonconservatively.	
Dilution is assumed to occur totally in the dolomite.	Dilution is assumed to occur at all locations.
<u>Disadvantage:</u> This approach conceivably may not be in accordance with recent IEPA regulations discussed above.	<u>Advantages:</u> This aspect represents physical realism in that the soil adjacent to the beam absorber has an initial concentration intrinsic to the radioactivation process and that all other effects (e.g., transport, decay, and mixing) further reduce the concentration in water. One can set $R(\text{Mix}) = R(\text{Dolomite}) = 1$ and thus not allow for any dilution in the dolomite or at its boundary with the till. This renders the model to be more favorable for demonstrating compliance with the new IEPA Groundwater Quality Standards discussed above.

## 7. Comparison of Calculations Made Using the SRWM and the CM

A number of calculations predicting potential groundwater concentrations have been performed over the years at Fermilab using the SRWM. In this section results using the proposed CM are compared with results obtained using the SRWM. For this purpose, five examples of SRWM calculations were selected based upon their "availability" to the author which provided values of  $S_{\text{max}}$ , as well as  $S_T$  without the need to redo the CASIM calculations. In the calculations used here, the value of  $S_{\text{max}}$  was obtained from a visual reading of the contour plots of star density with associated errors based upon "eyeball averaging," since the original CASIM printouts have long been recycled. References (Co 79a), (Co 79b), (Co 80), (Co 83), and (Co 87)<sup>15</sup> are the sources of information concerning these "test" cases.

<sup>15</sup>This reference represents the groundwater activation calculation for the antiproton target that was actually constructed with F-17 as the extraction point.

Table 3 is a Microsoft Excel™ spreadsheet on which the comparison is performed for several choices of parameters taken from the two models. To understand Table 3 requires considerable discussion of the specific parameters on a column-by-column basis. The rows of the table are simply the results for each of the references given at the bottom of the spreadsheet.

Place

The particular calculation concern numbered according to the reference list at the bottom of the spreadsheet.

d / (m)

This is the distance between the bottom of the "99% volume" and the top of the dolomite (in meters) to be used in the CM. As suggested in TM-1851, d is taken to be 1.84 meters less than the distance from the bottom of the enclosure or bathtub to the aquifer.

S-max / (stars/ml per prot.)

The maximum value of star density,  $S_{\max}$  (stars/cm<sup>3</sup> per incident proton), calculated to be external to the enclosure or bathtub as defined for the specific calculation.

L/H-3, w/H-3, L/Na-22, w/Na-22

The values of  $L_i$  and  $w_i$  to be used in Eq. (3) for <sup>3</sup>H and <sup>22</sup>Na, respectively. The values in the table will be discussed below along with the corresponding calculations.

C-o (H-3)/(pCi/ml-yr), C-o (Na-22)/(pCi/ml-yr)

The initial concentrations,  $C_{oi}$ , of <sup>3</sup>H and <sup>22</sup>Na, respectively, as calculated by Eq. (3) in pCi/cm<sup>3</sup>-yr per incident proton per year.

R(Till)/H-3, R(Till)/Na-22

The value of the reduction parameter R(Till) for <sup>3</sup>H and <sup>22</sup>Na, respectively. These values are discussed in more detail below.

C-f (H-3)/(pCi/ml-yr), C-f (Na-22)/(pCi/ml-yr)

The final concentrations,  $C_{fi}$  of <sup>3</sup>H and <sup>22</sup>Na, respectively, as calculated by Eq. (4) in pCi/cm<sup>3</sup>-yr per incident proton per year.

Test 1/Sumps

This gives the result of the weighted sum on the left-hand side of Eq. (1) comparing the  $C_{oi}$  values with the  $G_i$  values (DOE 5400.5) taken from Table 1 for surface discharges. This assumes the sumps are at the edge of the "99% volume".

### Test 2/Wells

This gives the result of the weighted sum from Eq. (1) comparing the  $C_{fi}$  values with the  $G_i$  values (DOE 5400.5) taken from Table 1 for drinking water at the till/dolomite interface. Here, no credit was given for either mixing at the till/dolomite interface or horizontal transport in view of the IEPA Groundwater Protection Standards. This is equivalent to setting  $R(\text{Mix}) = R(\text{Dolomite}) = 1$ .

### Test 3/Wells

This gives the result of the weighted sum from Eq. (1) comparing the  $C_{fi}$  values with the  $G_i$  values (40 CFR 141) taken from Table 1 for drinking water at the till/dolomite interface. Here, no credit was given for either mixing at the till/dolomite interface or horizontal transport in view of the IEPA Groundwater Protection Standards. This is equivalent to setting  $R(\text{Mix}) = R(\text{Dolomite}) = 1$ .

### CM-Sumps/Annual Protons

This gives the "annual proton limit" for the calculation based upon the concentrations in the surface discharges rendering the left-hand-side of Eq. (1) equal to unity. This "annual proton limit" does not include any averaging over time periods during which beam operations do not occur (see Section 8, "Recommendations to the Director").

### CM-Wells/Annual Protons

This gives the "annual proton limit" for the calculation based upon the concentrations in the wells (drinking water) rendering the left-hand-side of Eq. (1) equal to unity. It uses the most conservative result of Tests 2 or 3 which is, in practice, always Test 3. This "annual proton limit" does not include any averaging over time periods during which beam operations do not occur (see Section 8, "Recommendations to the Director").

### SRWM /Annual Protons

The annual limit on protons allowed based upon the calculation using the SRWM. This calculation is based upon the cited references and has not been redone specifically for this comparison.

### Remaining Parameters of the CM Model

- A. Those parameters not displayed on the spreadsheet that remain constant for all CM calculations are:

$$\rho_s = 2.25 \text{ g/cm}^3$$

$$K_{3H} = 0.075 \text{ atoms/star}^{16}$$

$$K_{22Na} = 0.02 \text{ atoms/star}^{16}$$

$$R(\text{Mix}) = R(\text{Dolomite}) = 1^{17}$$

- B. The crucial parameter of the entire CM calculation is  $R(\text{Till})$ . The work described in Ref. (WCC 93) and summarized in TM-1851 for the six sources which are above the dolomite (i.e., the prospective source "NUMI" is excluded), calculate these values for  $^3\text{H}$  as a function of parameter  $d$  based on detailed hydrogeologic model. The results are presented in Fig. 14 of TM-1851 and reproduced here as Fig. 1. The notations which label each of the curves in Fig. 1 are the various source locations studied in some detail by the *ad hoc* committee and Woodward-Clyde. Given the uncertainties in the modeling, both "representative" and "high end" results for  $R(\text{Till})$  are presented. While the modeling work of Woodward Clyde involves a sophisticated mathematical treatment, the "representative" results correspond to "slow" vertical migration and small values of  $R(\text{Till})$ , while the "high end" results correspond to more "rapid" vertical migration and large values of  $R(\text{Till})$ . In Appendix 2 of Ref. (WCC 93) the Woodward-Clyde Consultants make a formal, but not necessarily totally convincing argument, that the "representative", rather than "high end" velocities should be used.

For the "high end" situation, Fig. 15 of TM-1851 demonstrates that  $R(\text{Till})$  is fit quite well over the domain of  $8.5 < d < 18$  meters by the following equation:

$$R_{\text{high end}}(\text{Till}, H-3, d) = 1.703 \exp [-0.207 d (\text{meters})] . \quad (5)$$

Obviously, Eq. (5) cannot be used for small values of  $d$  since  $R(\text{Till})$  there would exceed unity. It is obvious from Fig. 1 that the choice of which velocity "family" (i.e., high end or representative) to use in the calculation of  $C_{fi}$  has tremendous importance as it can make differences of over six orders of magnitude in the results. A. Elwyn (El 94) has fit the "high end" calculations for the various sources described in Ref. (WCC 93) and TM-1851 with exponential fits constrained to achieve a value of  $R(\text{Till}, H-3, d)$

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<sup>16</sup> The values for  $K$  and  $L$  parameters are those based upon measurements in clay. No measurements exist for dolomite, but the values are assumed to be approximately the same.

<sup>17</sup> This assumption is consistent with the interpretation of the IEPA Groundwater Quality Standards discussed previously.

of unity at  $d = 0$ . These fits are displayed in Fig. 2. From these fits, it is reasonable to take the following equation for  $R(\text{Till}, H-3, d)$ :

$$R_{\text{high end}}(\text{Till}, H-3, d) = 1.0 \exp[-0.14 d (\text{meters})]. \quad (6)$$

The choice of Eq. (6), indeed, is a slightly conservative representation of the "high end" results, when the results of all the sources as seen in Fig. 2 are considered.

Likewise, A. Elwyn (El 94) has fit the values for the Neutrino area "representative" velocity calculation with a single exponential constrained to yield a value of  $R(\text{Till}, H-3, d)$  of unity at  $d = 0$  as shown in Fig. 3. The result is a so called "modified representative":

$$R_{\text{mod. rep.}}(\text{Till}, H-3, d) = 1.0 \exp[-1.026 d (\text{meters})]. \quad (7)$$

Since the Neutrino area "representative" calculation, (that is, the "N" source calculation in Fig. 1) gave the largest values of  $R(\text{Till})$  at any depth, this parameterization is reasonably conservative. [For the other sources, the coefficient of  $d$  in the exponential function ranges to negative values as large as in absolute value as 1.333.]

For  $^{22}\text{Na}$  the results for  $R(\text{Till})$  from Table 13 of Ref. (WCC 93) give values of  $R(\text{Till}) < 1.0 \times 10^{-8}$  for "representative" vertical flows. This small value essentially renders it unnecessary to consider the contribution of  $^{22}\text{Na}$  to possible drinking water contamination. For "high end" velocity conditions, A. Elwyn (El 94) was able to obtain a parameterization of  $^{22}\text{Na}$  migration for the MI40 source as shown in Fig. 4. Equation (8) fits the data rather well:

$$R_{\text{high end}}(\text{Till}, \text{Na}-22, d) = 1.0 \exp[-0.92 d (\text{meters})]. \quad (8)$$

The range in values between the choice of "high end" and "representative" velocities is obviously very large. Making the choice incorrectly can either greatly overestimate ("high end" 0 or underestimate ("representative") potential groundwater concentrations. Malensek, as documented detail in Appendix 1, has investigated this matter further and has identified a vertical migration velocity of 0.15 meter/year as a choice that is quite well-substantiated. Calculations of  $R(\text{Till})$  as a function of depth of the aquifer,  $d$ , using such a value were performed by A. Wehmann and it was found by A. Elwyn that the results could be well fit by exponentials as was done above that are normalized to a value of unity at  $d = 0$ . The results of these fits are shown in Fig. 5. Thus, this provides

an "intermediate" vertical velocity such that Eq. (9) can be applied

$$R_{\text{intermediate}} (\text{Till, H-3, d}) = 1.0 \exp [-0.3 d (\text{meters})]. \quad (9)$$

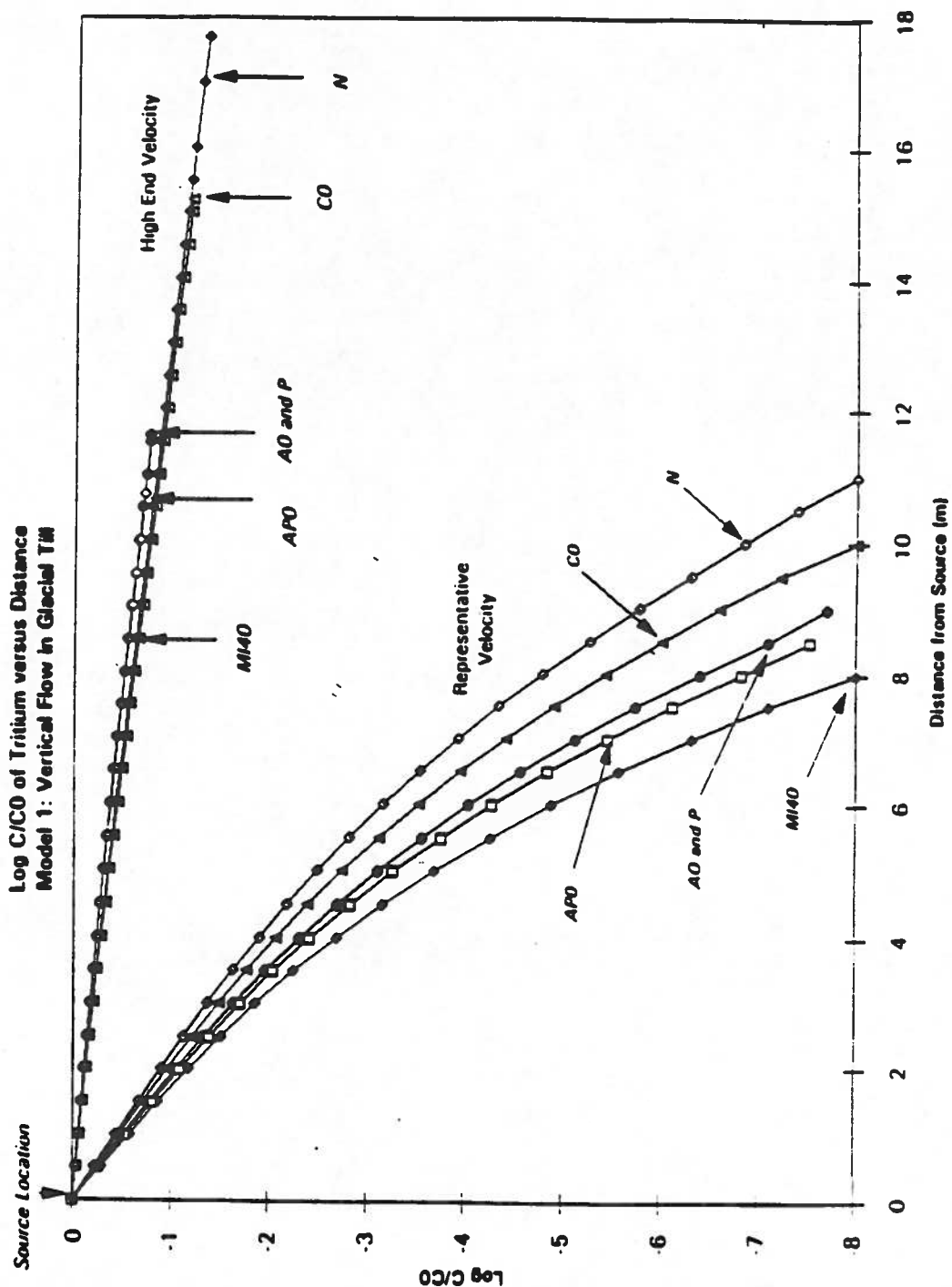
For this situation, Eq. (8) can be used to approximate the value of  $R(\text{Till})$  for  $^{22}\text{Na}$ .

- C. To perform a calculation using the CM, the values of  $L_i$  and  $w_i$  must be determined. Figure 6 reproduced from Fig. 4 of TM-1851 displays measured values of the fraction of the nuclides ( $L_i$ ) leached as a function of the weight of water as a fraction of soil weight ( $w_i$ ). The authors of TM-1851 recommend the choice of values where 99% of the nuclide of interest is leached. The choice of values where 98% of the nuclides of interest are leached was considered by the author of this report because it appears it is easier to read the corresponding values of  $w_i$  off the graph at that value of the leaching fraction  $L_i$ . The fraction of the total  $^{22}\text{Na}$  produced which was considered by the present author to be ultimately leachable was taken to be 15% while 100% of the  $^3\text{H}$  produced was considered ultimately leachable. As is stated on page 62 of TM-1851 and illustrated by Fig. 6, a large fraction of the activity eventually available for leaching, particularly for  $^3\text{H}$  but also to large degree for  $^{22}\text{Na}$ , can be removed from the soil with much less water than that quantity required to leach 98 or 99%. This can lead to larger values of  $C_{oi}$  and thus for  $C_{fi}$ . Thus one can choose alternative values of, say,  $L_i = 0.90$  and the corresponding values of  $w_i$  to obtain more conservative estimates of the concentrations. In TM-1851, this choice is stated to increase  $C_{oi}$  for  $^3\text{H}$  by about a factor of two. In view of the results concerning leachability, it appears to be prudent to use the  $w_i$  values that correspond to  $L_i = 0.90$ . These are the values that were used in the analysis summarized in Table 3.

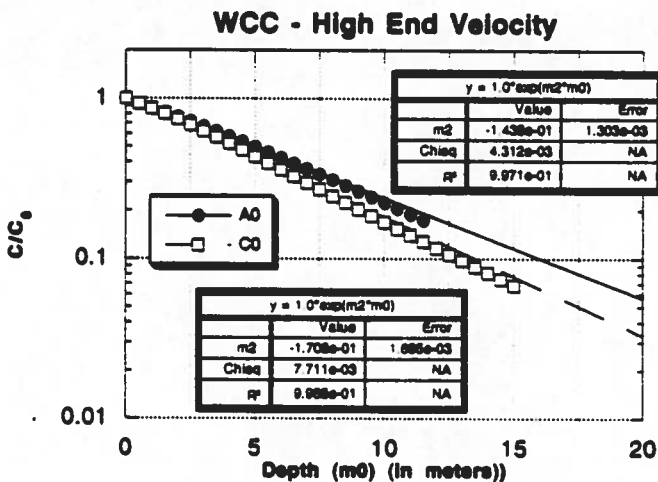
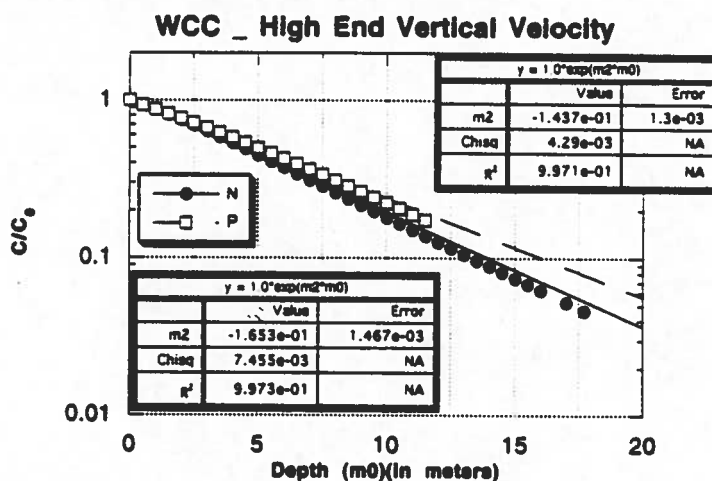
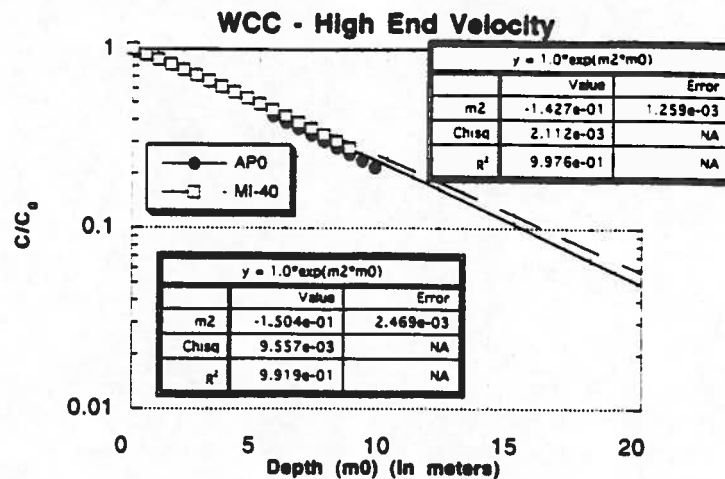
**Table 3 Comparison of Results Using Alternative Parameters in the Concentration Model with Results Obtained using the SRWM**

Place	d	S-max	L	w	L	w	C-o (H-3)	C-o (Na-22)	R(TiII)	R(TiII)	C-4 (H-3)	C-4 (Na-22)	Test 1	Test 2	Test 3	CM-Sumps	CM-Well	SRWM
	m	(eins/ml per prot.)	H-3	H-3	Na-22	Na-22	(pCi/ml-yr)	(pCi/ml-yr)	H-3	Na-22	(pCi/ml-yr)	(pCi/ml-yr)	Sumps	Wells	Wells	Annual	Annual	Annual
																Protons	Protons	Protons
"High End" vertical velocity [R(TiII, H-3) = 1.0*EXP(-0.14*d(meters)), R(TiII, Na-22) = 1.0*EXP(-0.92*d(meters))]:																		
1	10.0	1.00E-11	0.90	0.27	0.135	0.52	1.80E-20	3.75E-22	2.45E-01	9.76E-05	4.43E-21	3.66E-26	4.65E-23	5.54E-23	2.21E-22	2.15E+22	4.52E+21	1.38E+20
2	12.3	6.00E-08	0.90	0.27	0.135	0.52	1.08E-16	2.25E-18	1.78E-01	1.19E-05	1.93E-17	2.68E-23	2.79E-19	2.41E-19	9.64E-19	3.59E+18	1.04E+18	1.00E+18
3	12.8	1.50E-08	0.90	0.27	0.135	0.52	2.71E-17	5.62E-19	1.67E-01	7.83E-06	4.52E-18	4.40E-24	6.87E-20	5.65E-20	2.26E-19	1.43E+19	4.42E+18	1.44E+19
4	17.0	3.00E-08	0.90	0.27	0.135	0.52	5.41E-18	1.12E-19	9.19E-02	1.54E-07	4.98E-18	1.74E-26	1.39E-20	6.22E-21	2.49E-20	7.17E+19	4.02E+19	3.64E+19
5	16.4	1.00E-08	0.90	0.27	0.135	0.52	1.80E-17	3.75E-19	1.00E-01	2.71E-07	1.81E-18	1.01E-25	4.65E-20	2.26E-20	9.03E-20	2.15E+19	1.11E+19	3.41E+18
"Intermediate" vertical velocity [R(TiII, H-3) = 1.0*EXP(-0.3*d(meters)), R(TiII, Na-22) = 1.0*EXP(-0.92*d(meters))]:																		
1	10.0	1.00E-11	0.90	0.27	0.135	0.52	1.80E-20	3.75E-22	4.92E-02	9.76E-05	8.88E-22	3.66E-26	4.65E-23	1.12E-23	4.44E-23	2.15E+22	2.25E+22	1.38E+20
2	12.3	6.00E-08	0.90	0.27	0.135	0.52	1.08E-16	2.25E-18	2.48E-02	1.19E-05	2.68E-18	2.68E-23	2.79E-19	3.36E-20	1.34E-19	3.59E+18	7.45E+18	1.00E+18
3	12.8	1.50E-08	0.90	0.27	0.135	0.52	2.71E-17	5.62E-19	2.16E-02	7.83E-06	8.95E-19	4.40E-24	6.87E-20	7.03E-21	2.89E-20	1.43E+19	3.42E+19	1.44E+19
4	17.0	3.00E-08	0.90	0.27	0.135	0.52	5.41E-18	1.12E-19	6.01E-03	1.54E-07	3.25E-20	1.74E-26	1.39E-20	4.07E-22	1.63E-21	7.17E+19	6.15E+20	3.64E+19
5	16.4	1.00E-08	0.90	0.27	0.135	0.52	1.80E-17	3.75E-19	7.22E-03	2.71E-07	1.30E-19	1.01E-25	4.65E-20	1.63E-21	6.51E-21	2.15E+19	1.54E+20	3.41E+18
"Modified Representative" vertical velocity [R(TiII, H-3) = 1.0*EXP(-1.026*d(meters))]:																		
1	10.0	1.00E-11	0.90	0.27	0.135	0.52	1.80E-20	3.75E-22	3.37E-22	1.00E-08	6.08E-25	3.75E-30	4.65E-23	7.61E-27	3.04E-26	2.15E+22	3.29E+25	1.38E+20
2	12.3	6.00E-08	0.90	0.27	0.135	0.52	1.08E-16	2.25E-18	3.23E-06	1.00E-08	3.49E-22	2.25E-26	2.79E-19	4.42E-24	1.75E-23	3.59E+18	5.72E+22	1.00E+18
3	12.8	1.50E-08	0.90	0.27	0.135	0.52	2.71E-17	5.62E-19	2.02E-06	1.00E-08	5.47E-23	5.62E-27	6.87E-20	6.97E-25	2.73E-24	1.43E+19	3.66E+23	1.44E+19
4	17.0	3.00E-08	0.90	0.27	0.135	0.52	5.41E-18	1.12E-19	2.53E-08	1.00E-08	1.37E-25	1.12E-27	1.39E-20	4.53E-27	6.86E-27	7.17E+19	1.46E+26	3.64E+19
5	16.4	1.00E-08	0.90	0.27	0.135	0.52	1.80E-17	3.75E-19	4.74E-08	1.00E-08	8.55E-25	3.75E-27	4.65E-20	2.01E-26	4.27E-26	2.15E+19	2.34E+25	3.41E+18
1	(Co 87) J. D. Cossairt and P. M. Yurieta, "Shielding Calculations for the Antiproton Target Area", TM-1136, September, 1987.																	
2	(Co 76a) J. D. Cossairt, "Radiation Safety Implications of the Proposed Main Ring/Energy Doubler Abort", TM-902, September 10, 1979.																	
3	(Co 76b) J. D. Cossairt, "Review of the Shielding Requirement of the E-497 Target Magnet", TM-911, October 4, 1979.																	
4	(Co 80) J. D. Cossairt, "Soil Activation Calculation for the Proposed Nourira Front Hall", TM-945, January 15, 1980. (Used maximum star density at bathtub)																	
5	(Co 83) J. D. Cossairt, "Shielding of Tevatron Meson Laboratory target piles-M-West, M-Center, M-Polarized", TM 1235, December, 1983																	

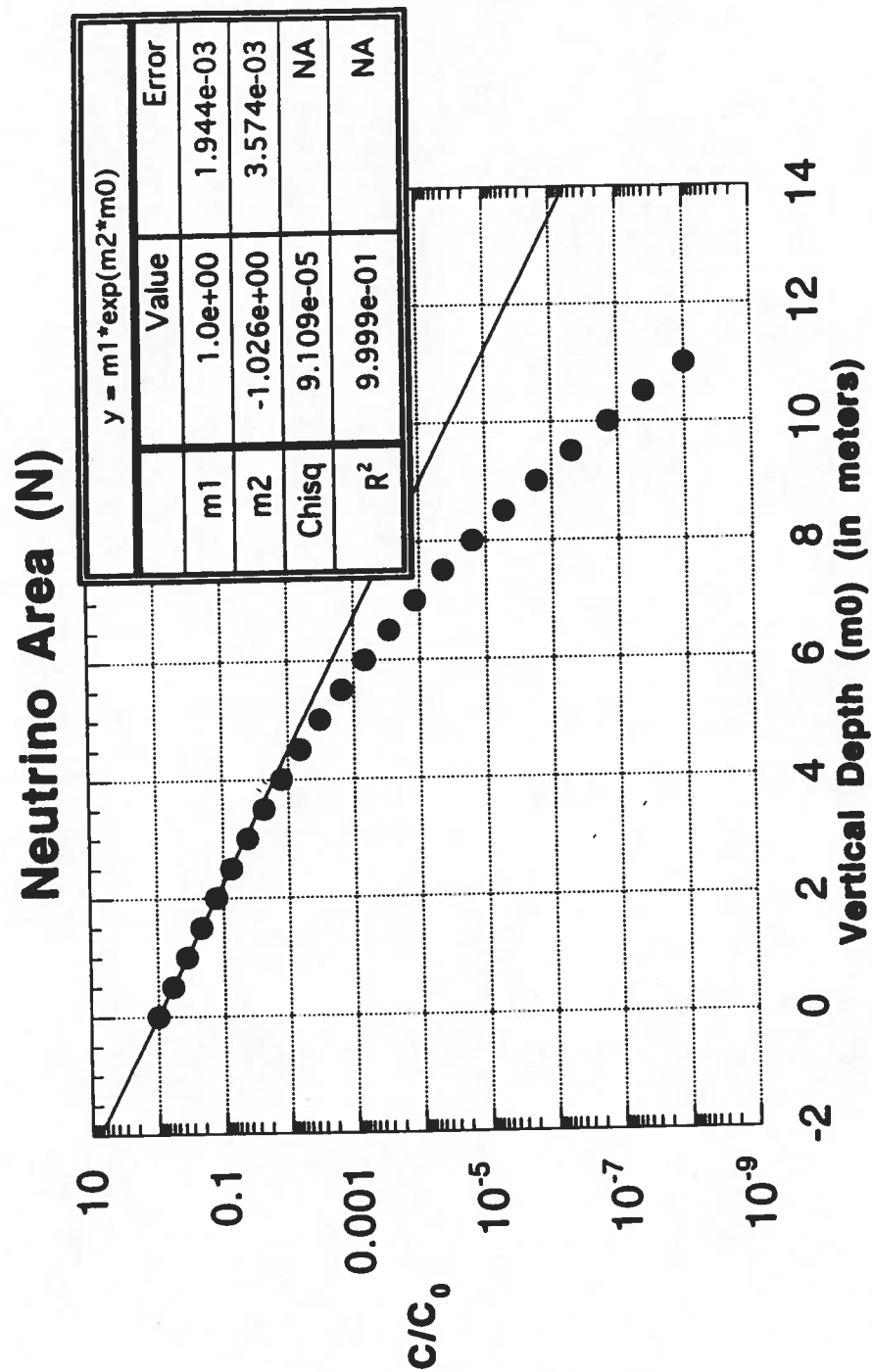
**Figure 1** Concentration Ratios for the Seven Sources Considered in TM-1851 Versus Distance to the Till/Dolomite Interface (Reproduction of Fig. 14 from TM-1851)



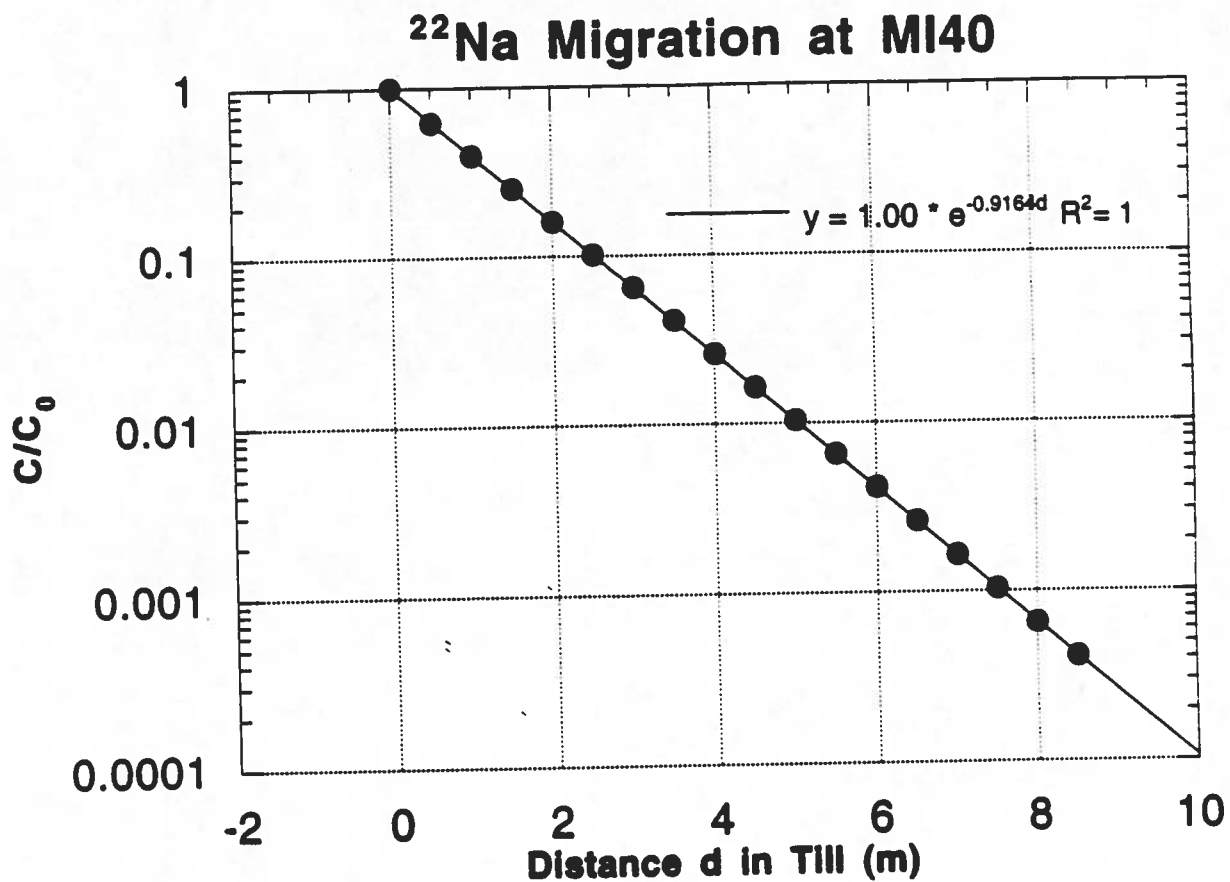
**Figure 2 Exponential Fits to Ref. (WCC 93) Results for "High End" Velocity Conditions for the Various Sources Studied for  $^3\text{H}$**



**Figure 3 Exponential Fits to Ref (WCC 93) Results for "Representative" Velocity Conditions for the Neutrino Area for  $^3\text{H}$**



**Figure 4 Exponential Fits to Ref (WCC 93) Results for "High End" Velocity Conditions for the MI 40 Source for  $^{22}\text{Na}$**



**Figure 5 Exponential Fits to Malensek's Results for "Intermediate" Velocity Conditions for Various Sources Studied for  $^3\text{H}$ .**

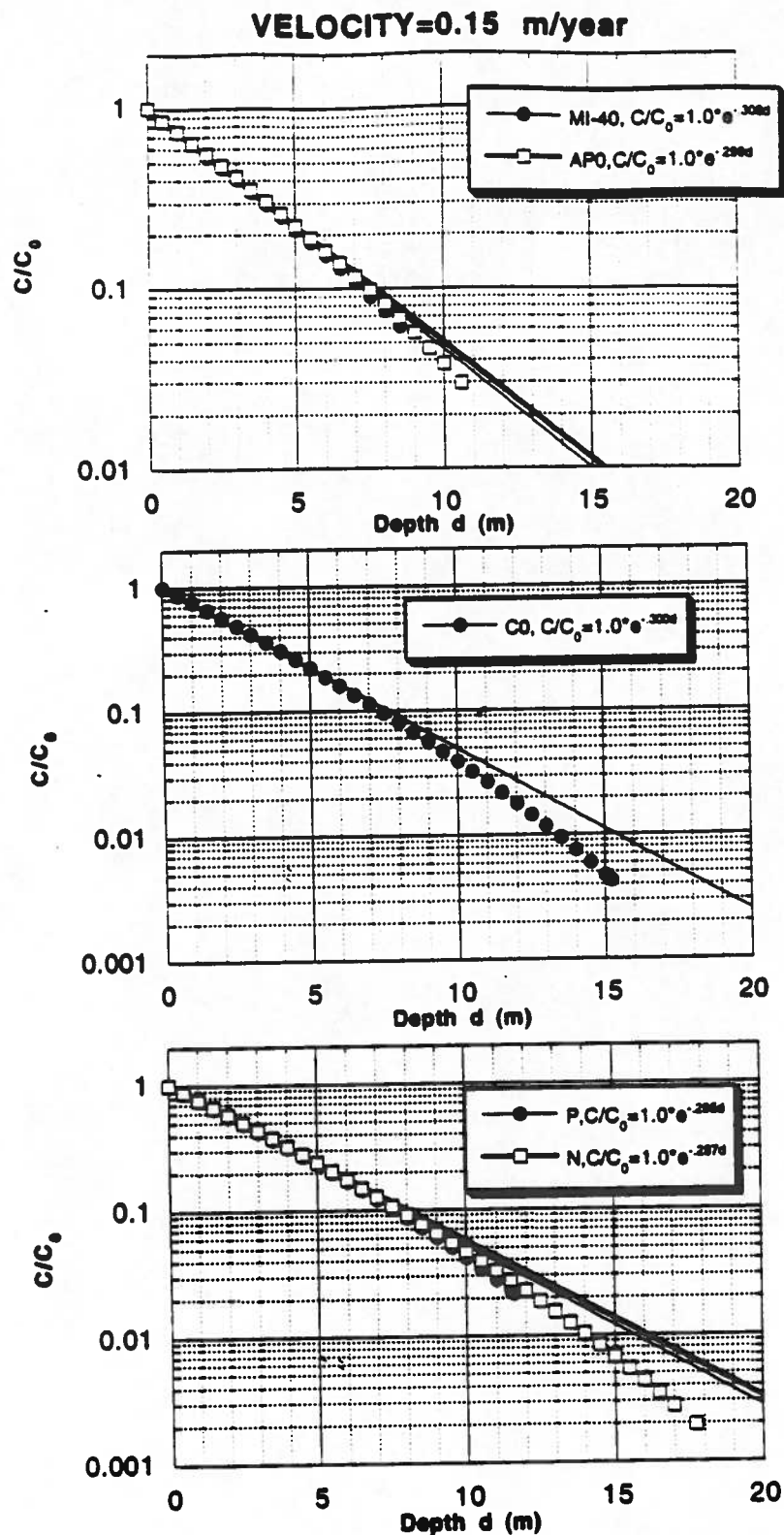
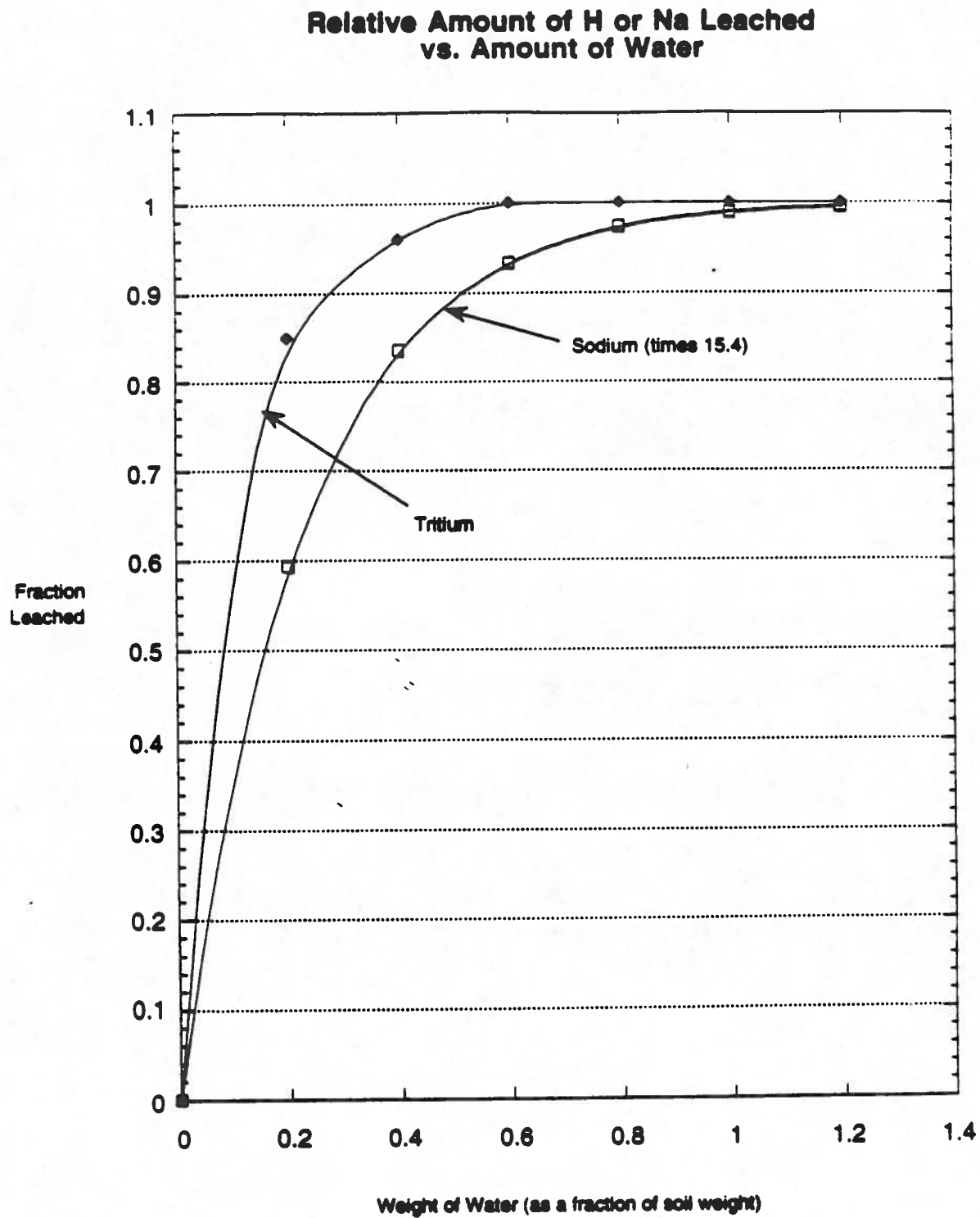


Table 3, therefore, gives parameters and calculations based upon three choices for the vertical velocities, denoted "high end", "intermediate", and "modified representative." For each choice of vertical velocity the dilution corresponding to 90% leaching was taken. The exponential functions described above used to approximate the vertical migration as modeled in detail by the authors of Ref. (WCC 93) are displayed above each set of results. The calculations are followed through to the determination of the annual proton limits so that comparisons can be made with the results obtained using the SRWM. As anticipated, the results obtained using the "representative" vertical velocities yield very small values of  $R(\text{Till})$  at the till/dolomite interface and hence very large annual proton limits. On the other hand, the calculations in which the "high end" vertical velocities are used yield annual proton limits for wells that are comparable to those obtained with the SRWM. As a general, but not universal, rule, the CM even with the choice of the "high end" vertical migration velocities, gives larger annual proton limits than does the SRWM. In all cases studied using the well-substantiated choice of "intermediate" migration velocity, the same or larger annual proton limits are obtained using the CM than the SRWM.

**Figure 6 Leaching Curves for Sand and Gravel Reproduced from Figure 4 of TM-1851**



## 8. Recommendation to the Fermilab Director

As Senior Laboratory Safety Officer, I have reviewed the existing Single Resident Well Model (SRWM) and the proposed Concentration Model (CM). As discussed in detail above, it is my belief that the Concentration Model has many advantages and is much more defensible than is the SRWM. The latter certainly presents a more realistic picture of the actual phenomena present. In the present era of environmental scrutiny, to err on the side of conservatism is to be consistent with historic Fermilab policy and prudent in view of the extensive and detailed public interest in environmental protection, particularly with respect to water quality. Environmental protection standards are frequently being revised, generally in the direction of increased conservatism. Also, the standards are being revised to become more inclusive of media "close to the source." I conclude that Fermilab would be well advised to choose a conservative approach. This approach could be modified in future years if further measurements of soil activation and groundwater migration are conducted. Indeed, such measurements and improved calculations could be of significant benefit in resolving some of the issues identified in this report and its references. Alternatively, such detailed measurements and calculations could be very helpful in resolving these uncertainties for specific designs. However, it is probably not practical to perform such studies for all potential designs.

Given the nature of the present body of data, I recommend that Fermilab choose a "cookbook" parameterization of the results of the work of the *ad hoc* committee as a cost effective alternative to the use of outside consultants exemplified by Woodward-Clyde to provide for the analysis of every potential beam absorber location and design. It appears to me that the parameterizations described in this report are adequate for nearly all beam absorber designs. However, the software used by WCC ("PATCH-3D") is available for use at Fermilab and can certainly be employed in a manner consistent with the proposal I offer here.

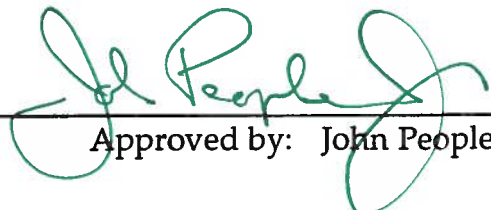
I, therefore, recommend for approval by the Director the following "recipe" for conducting groundwater activation calculations at Fermilab:

- The CM model is to be used as outlined in the present report, its appendix, and in TM-1851. This includes the specifications given in TM-1851 of all parameters not specifically discussed below.
- The value of  $N_p$  chosen should be representative of the average annual proton delivery. Given the nature of the Fermilab operations cycle, it is recommended that this average be taken over a three year period.
- $L_i$  should be taken to be 0.90 and the corresponding value of  $w_i$  should be used.

- The "Intermediate" vertical migration parameterization stated in this present report (Eq. 6) is to be used to calculate  $R(\text{Till})$ .
- The value of  $R(\text{Dolomite})$  shall be taken to be unity.
- The annual limit on protons (i.e.,  $N_p$ ) shall be the lower of the two values determined separately from the surface water and drinking water criteria. The criteria to be used are those listed in Table 1 derived from DOE 5400.5 for surface water and in 40 CFR 141 (current version) for drinking water.
- Proponents of designs where the performance of radioactivation calculations based upon these recommendations is either intrinsically non-feasible or problematic in some other way shall document their objections, and carry out alternative documented methods of calculation. The resulting report shall be submitted to the Senior Laboratory Safety Officer for review. The Senior Laboratory Safety Officer will then make a recommendation for approval or disapproval to the Director. The Director shall make the final determination.
- Since boreholes can short circuit the glacial till, they form a potential path between the target areas and the aquifer. All requests for wells and borings, and their deposition after drilling is completed shall be submitted with the approval of the Environment, Safety, and Health Section.
- Upon approval of this proposal, a modification of Appendix 12B of Chapter 12 of *The Fermilab Radiological Control Manual* (FRCM) shall be drafted by the staff of the Environment, Safety, and Health Section and reviewed in accordance with procedures of *The Fermilab ES&H Manual* of which the FRCM is a part.

  
Prepared by: J. Donald Cossairt

12/15/94  
Date:

  
Approved by: John Peoples, Jr.

12/22/94  
Date:

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## Appendix 1



Fermi National Accelerator Laboratory  
P.O. Box 500 • Batavia, Illinois • 60510

11/28/94

To: Don Cossairt  
From: Anthony Malensek *AM*  
Subject: Groundwater Migration Models

The following describes our best knowledge of the site specific factors that affect the velocity in the glacial till--v(Till). The velocity is a combination of the gradient (I), the hydraulic conductivity (K), and the effective porosity(n). Each component is addressed individually.

$$v = \frac{i * K}{n}$$

### The gradient I:

In Appendix 2 of the WCC report, I is calculated from wells F-39a and F-39c, near Frelo Field. The data comes from five measurements over an eight year period, 1984-1992. Borehole logs were also used to calculate I for the cross sections at Sources A0, C0, P, and MI-40. The average for all of these is I=0.40, with small deviations.

### The porosity n:

Section 5.1.1.5 of the WCC report discusses n and says the porosity is based on STS(82)<sup>1</sup>. That was a report on the B0 excavation project listing a water content of 18%. In a completely separate report STS(78)<sup>2</sup>, the moisture content of ten samples at AP0 gave an average water content of 16%. By converting the water content (given as a percent by weight) into porosity, the average of 16% translates into n =0.36.

### The hydraulic conductivity K:

The best data come from STS(78). That report lists the results of ten measurements of K at AP0. Five are from one soil boring, five from another. Each set covers the full range of depth into the till--13 ft to 65 ft below the surface. The highest value of the ten measurements gives, K = 2.84E-7 cm/sec = 0.09 m/yr.

### CONCLUSION:

Using the above values for I, n and K that are defensible and supported by data taken at the Fermilab site, a reasonable value can be calculated for the most likely average velocity in the glacial till.  $v = (0.4) * (0.09 \text{ m/yr}) / 0.36 = 0.10 \text{ m/yr}$ . If values different from the averages of I and n are chosen (K is already taken at the high end), then the velocity could increase to 0.15 m/yr.

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<sup>1</sup>STS Memo, "Permeability Test Results", November 10, 1982.

<sup>2</sup>STS Memo, "Additional Ground Water Flow Study, Anti-Proton Target Area, Fermi National Accelerator Laboratory, near Batavia, Illinois", August 31, 1978.

## Appendix 2



**Fermilab**  
ES&H Section

December 5, 1994

TO: Ray Stefanski  
FROM: Don Cossairt *DC*  
SUBJECT: Proposed Use of Concentration Model for Calculating the Radioactivation of Soil and Groundwater at Fermilab

Enclosed is a report documenting my review of the concentration model proposed by the *ad hoc* groundwater committee. This report includes a synopsis of the model, a comparison with the method used previously to do such calculations at Fermilab, comparisons of the results obtained with specific calculations, and a recommendation to the Director which represents my conclusions as to how this model can be sensibly used at Fermilab. It is certainly a more realistic model than used heretofore. This report has been revised in view of the discussion generated as a result of an oral presentation I made on June 16, 1994. The discussion led to a modification that significantly increases the level of "realism" of the proposed usage of the model. Yet, with the choices included in my recommendation it can, I believe, provide sufficient protection of water supplies.

Previous versions of this document, which were substantially the same as this version, have been reviewed by members of the *ad hoc* groundwater subcommittee and by Larry Coulson. I now am submitting this revised version to you for your recommendation for approval (below) or for your additional comments. Since this subject is rather complicated, if you agree with my recommendations, it might be best to present this to the Director in person.



Recommend for Approval

*12/22/94*

Date

Encl.

cc: D. Boehnlein, w/encl.  
L. Coulson, w/encl.  
T. Miller, w/encl.  
R. Walton, w/encl.  
File: Groundwater Monitoring, w/encl.